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connection with Application No. PP 1392 for a patent by CRC FOR POLYMERS
PTY. LTD. filed on 19 January 1998.



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PROVISIONAL SPECIFICATION

for the invention entitled:

"Process for Increasing the Melt Strength of Polypropylene (2)"

The invention is described in the following statement:

PROCESS
FOR INCREASING THE MELT STRENGTH OF POLYPROPYLENE
(2)

5

The present invention relates to polypropylene homopolymers and copolymers. In particular, the present invention relates to a process for increasing the melt strength and/or the extensional melt viscosity of said polymers by melt phase processing.

- 10 The melt strength and extensional viscosity of linear or straight chain polymers, such as polypropylene, decreases rapidly with temperature. By contrast, polymers such as low density polyethylene which are highly branched retain relatively high melt strengths and extensional viscosities. It is generally understood that the difference in melt strengths and extensional viscosities is attributable to the presence of long chain branching in polymers
- 15 such as low density polyethylene. Long chain branching allows a greater degree of chain entanglement.

A number of methods for increasing the melt strength/extensional viscosity of polypropylene and related polymers through the introduction of branching or a limited

20 degree of crosslinking in a process involving reactive extrusion have been proposed and are summarised in a recent paper by Wang et al. (Wang, X., Tzoganakis, C., and Rempel, G.L., *J. Appl. Polym. Sci.*, 1996, 61, 1395). One such process involves the reactive extrusion of polypropylene with a polyfunctional monomer/initiator combination. For example, the use of pentaerythritol triacrylate in combination with 2,5-dimethyl-2,5-

25 di(t-butylperoxy)hexane (DHBP).

White (US 5578682) has disclosed the use of various polyunsaturated crosslinking agents (for example, bismaleimide derivatives) in combination with free radical initiators to achieve an increase in the melt strength various polymers.

30

It is well known that the melt phase processing of polypropylene leads to mechanochemical degradation. The processing of polypropylene in the presence of free radical initiators provides an increased rate of degradation. This controlled degradation of polypropylene is used commercially for the production of controlled rheology resins

having reduced polydispersity and reduced die swell (Lambla, M. in *Comprehensive Polymer Science*, Pergamon, New York 1992, vol Suppl. 1, p 619; Hogt, A.H., Meijer, J., Jelinic, J. in *Reactive Modifiers for Polymers*, Al-Malaika, S. Ed., Chapman & Hall, London, 1996, p 84.). The degradation of polypropylene as described therein results in a
5 lowering of melt strength.

The batch modification of polypropylene to produce crosslinked (insoluble) polypropylene by treatment with peroxides is described by Borsig et al. (Borsig, E., Fiedlerova, A., Lazar, M. J., *Macromol. Sci, Chem.*, 1981, -A16, 513). Initiators which produce
10 benzoyloxy radicals or phenyl radicals are described as being more efficient in inducing crosslinking or grafting than those which produce t-butoxy or alkyl radicals. The process requires the use of high levels of peroxide. The use of polyfunctional monomers as coagents to retard degradation and enhance crosslinking is described by Chodak, I.; Fabianova, K.; Borsig, E.; Lazar, M. *Agnew. Makromol. Chem.*, 1978, 69, 107.

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DeNicola (EP 384331A2) has disclosed a means to produce a branched propylene polymer material showing a nett increase in the weight average molecular weight by solid state modification of predominantly isotactic semi-crystalline linear polypropylene. The process described in EP384331A2 involves blending peroxides with short half lives (eg peroxy
20 dicarbonates) with linear propylene polymer in a mixing vessel at temperatures from 23°C to 120°C in an inert atmosphere and continuing to mix for a period of time until the peroxide decomposes and polymer fragmentation and branching occurs without significant gelation of the polymer. DeNicola states that at temperatures greater than 120°C no branching or melt strength enhancement is achieved.

25

U.S. 5,464,907 teaches that certain unsaturated peroxides may be used to induce grafting in polypropylene and α -olefin copolymers. They report that use of other peroxides generally results in chain degradation.

Polypropylene is also known to undergo substantial degradation during melt phase grafting of monofunctional monomers, for example maleic anhydride and glycidyl methacrylate. It has also been reported that the degradation that accompanies grafting of these monomers to polypropylene may be reduced by the addition of relatively high concentrations of certain comonomers including styrene (see, for example Sun, Y.-J., Hu, G.-H., and Lambla, M., *Angew. Makromol. Chem.*, 1995, 229, 1; Chen, L-F., Wong, B. and Baker, W.E. *Polym. Eng. Sci.* 1996, 36, 1594.) Sun et al. report that there is degradation (as indicated by an overall decrease in molecular weight) when styrene alone is grafted onto polypropylene even when a relatively high concentration is used (4 moles/100g PP).
5
10 Either 2,5-dimethyl-2,5-(t-butylperoxy)hex-3-yne or 2,5-dimethyl-2,5(t-butylperoxy-hexane(DHBP) was used as the initiator in these experiments.

We have found that, with appropriate choice of conditions, melt mixing of polypropylene homopolymer or ethylene-polypropylene copolymer in the presence of an initiator selected from the group consisting of dibenzoyl peroxide (BPO), tert-butyl peroxybenzoate (TBPB) and mixtures thereof, and monoene monomer(s) provides one or more of the following:
15 increased melt strength; increased extensional viscosity; increased molecular weight; and broadened molecular weight distribution.

20 According to the present invention there is provided a process for modifying a polypropylene (co)polymer wherein said process comprises melt mixing the polypropylene (co)polymer in the presence of an initiator selected from the group consisting of benzoyl peroxide, tert-butyl peroxybenzoate and mixtures thereof, and at least one monomer in an effective amount. Advantageously the thus formed modified polypropylene may be
25 obtained without the associated production of gels.

Polymers suitable for use in the present invention include a wide variety of polypropylene homopolymers, copolymers and blends containing one or more polypropylene homopolymers and/or copolymers.

Suitable polypropylene homopolymers include isotactic polypropylene, atactic polypropylene and syndiotactic polypropylene. Commercial isotactic polypropylene having a proportion of mesodyeds of greater than 90% is preferably used in the process of the present invention. Isotactic polypropylene is a semi-crystalline polymer having a number of properties which have made it one of the most widely used commercial polymers. These properties include heat resistance, stress cracking resistance, chemical resistance, toughness, and low manufacturing costs. However, the melt strength of isotactic polypropylene as measured directly by extensional viscosity or use of a commercial melt strength tester or indirectly by more qualitative measures such as drop time or die swell ratio is relatively low. This relatively low melt strength limits the use of polypropylene in applications such as foam extrusion, thermoforming and film blowing. In order to use polypropylene in such applications it is necessary to employ sophisticated processing equipment. The present invention now permits this already widely used commercial polymer to be used in an even wider range of applications.

15

Polypropylene copolymers include copolymers of propylene and other monomers with such other monomers being present preferably in amounts of up to 10%wt/wt. A preferred comonomer is ethylene.

20 The present invention is also applicable to other linear α -olefins. It is preferable that any such other linear α -olefins are present in the polymer to be modified in amounts in excess of 90%wt/wt.

The preferred initiators are BPO and TBPB. BPO offers the greatest enhancement in properties for a given concentration. However, t-butyl peroxybenzoate may be used to advantage in the process of the present invention. One advantage of the use of t-butyl peroxybenzoate over benzoyl peroxide is that a higher processing temperature may be used without significant decomposition of the peroxide. This allows for more thorough mixing and a reduction in the likelihood of the formation of gels.

30

- The amount of initiator and monomer used in the process of the present invention should be an effective amount to achieve the desired increase in melt strength. Melt strength is considered in the art to be an indication of long-chain branching in polyolefins. It is preferable in the process of the present invention that long-chain branching predominates
5 over crosslinking in the reaction between the initiator and the polypropylene (co)polymer. Crosslinking of the polypropylene (co)polymer may result in the formation of gels which disrupt the appearance of the polypropylene (co)polymer. In the process of the present invention it is desirable to control the degree and distribution of crosslinking and keep the level of crosslinking as uniform and as low as necessary to produce the desired effects.
- 10 The amount of crosslinking which occurs in the polypropylene (co)polymer is dependant upon the amount of initiator and monomer melt mixed with the polypropylene (co)polymer. The amount of crosslinking is also dependent upon the degree of mixing as any regions high in initiator and monomer concentration will result in excessive localised crosslinking and the formation of gels. It is desirable that good distributive and dispersive
15 mixing be employed to promote even distribution of the initiator and monomer in the polypropylene (co)polymer so as to minimise the variation in initiator and monomer concentration throughout the polypropylene (co)polymer and reduce the likelihood of the formation of gels.
- 20 Preferably the initiator will be present in the range of from 0.1 to 5% by weight of the polypropylene homopolymer or copolymer ((co)polymer). The more preferred range being from 0.15% to 2.0% wt/wt of the polypropylene (co)polymer and even more preferred range being from 0.15 to 1.8% wt/wt of the polypropylene.
- 25 The initiator is preferably introduced into the polymer melt directly, either neat (as a powder or a liquid), dispersed or dissolved in a suitable medium (for example, dissolved in 2-butanone) or adsorbed on polymer pellets or powder which are added as a masterbatch. It is desirable that the initiator is rapidly mixed with the polymer melt at a rate in keeping with the half life of the initiator at the processing temperature of the
30 polypropylene (co)polymer.

The initiator may be added either alone, or along with the polypropylene (co)polymer, or with any other polymer, additive or filler, so that the polymer melts and mixes with the initiator as it is decomposing. When the initiator is fed to the main feed throat of the
5 extruder it is preferred to have a barrel temperature which is relatively low in the region adjacent to the main feed throat and increases towards the die to prevent premature decomposition of the peroxide.

It will be understood by those skilled in the art that by the term "monoene monomer" it is
10 meant a monomer having a single reactive double bond.

The preferred monoene monomer(s) or mixtures thereof include vinyl monomers of structure $\text{CH}_2 = \text{CHX}$ where X is chosen so as to confer the desired reactivity and solubility.

15

The more preferred monomers are aromatic monomers. The most preferred monomer is styrene. The amount of monomer will preferably be up to 5 times the total moles of initiator added to the polypropylene (co)polymer. The most preferred range being 1 to 4 times the total moles of initiator added to the polypropylene (co)polymer.

20

The monoene monomer may be added with the polypropylene (co)polymer or it can be added prior to the initiator, with the initiator or subsequent to the initiator. However it is preferred to have the monomer mixed and dispersed into the polymer melt before the initiator has substantially decomposed. The monoene monomer is preferably introduced
25 into the polymer melt directly, either neat (as a powder or a liquid), dispersed or dissolved in a suitable medium (for example, dissolved in 2-butanone) or adsorbed on polymer pellets or powder which are added as a masterbatch.

The processability and other properties of the product may be improved by a chain
30 scission step following the initial polymer modification step. This may be carried out by:

- a) adding one or more additional initiators with or subsequent to the first initiator addition;
- b) the use of high shear mixing;
- c) the use of high temperatures;
- d) the use combination is of one or more of (a) - (c) above.

5

This additional step in the production of a polymer enables tailoring the properties of the product to meet the requirements of the desired application. For example, by this two stage process it is possible to produce materials with similar melt viscosity to the base polymer but a substantially increased melt strength. Use of the single stage process
10 generally provides both an increase in melt strength and an increase in melt viscosity (see examples)

One or more additional initiators may be added to the polypropylene (co)polymer during the modification process either with or subsequent to the initiator and monomer addition.
15 The additional initiator is typically added to give chain scission of the polypropylene (co)polymer so as to decrease the melt viscosity and improve the processability of the modified polypropylene (co)polymer. The additional initiator should be introduced to the polymer melt after the first initiator or have a sufficiently long half-life relative to the first initiator such that its decomposition can be staged to occur after the initial polymer
20 modification process. In some instances a polypropylene (co)polymer modified in accordance with the present invention may have a $MFI < 1$ g/10 min. With use of the additional initiator an $MFI > 1$ g/10 min may be achieved. The additional initiator may be selected from the group consisting of 2,5-dimethyl-2,5-di(t-butylperoxy)hexane (DHBP), dicumyl peroxide (DCP), t-butyl peroxy-2-ethylhexonate(TBEH), and dilauryl
25 peroxide (DLP) or any other peroxide which can result in the overall chain scission of the polypropylene (co)polymer during melt processing. While the improvement in processability through chain scission normally results in some decrease in the melt strength/extensional viscosity of the modified polypropylene (co)polymer, the melt strength/extensional viscosity may still be acceptable, and improved over the unmodified
30 polypropylene (co)polymer.

It is possible to combine the process of the present invention with other processes of polymer modification or with, for example, the addition of fillers, additives or stabilisers, or blending with other polymers. [which do not substantially interfere with the improved
5 properties afforded by the process of the present invention].

In the process of the present invention the polypropylene (co)polymer is melt mixed in the presence of initiator and monomer. Melt mixing may be carried out by any convenient means capable of mixing the polypropylene (co)polymer at temperatures above the melting
10 point of the polypropylene (co)polymer.

Suitable apparatus for melt mixing the polypropylene (co)polymer include continuous and batch mixers. Suitable mixing equipment includes extruders such as single screw and twin screw extruders, static mixers, cavity transfer mixers and combinations of two or more
15 thereof. It is preferred that the melt mixing is conducted in either a co- or counter-rotating twin screw extruder.

The barrel set temperatures are preferably in the range 80-280°C. Typical melt temperatures are in the range 170-290°C.

20

In order to optimise the melt strength/extensional viscosity, the preferred melt temperatures are in the range 160°C to 220°C. This range provides optimal properties whilst minimising the amount of chain scission which occurs during processing. However, in some cases it may be desirable to use higher temperatures such as in the
25 venting/discharge sections of single screw or twin screw extruders or to induce some chain scission in order to decrease the molecular weight of the modified polypropylene (co)polymer and improve the processability of the modified polypropylene (co)polymer.

Typically, the die temperatures are in the range 180-290°C.

30

Preferably the extrusion conditions are adjusted so that the polypropylene (co)polymer, initiator/monomer mixture are conveyed as quickly as possible into the melting/mixing zone to maximise the melt phase reaction (eg for twin screw extruders - high throughput rates, higher screw speeds under starve fed conditions). It is more preferred that the
5 additives are added to and mixed with molten polypropylene (co)polymer to further enhance the melt phase reaction. Preferably residence times in the range of from 10 seconds to 5 minutes are selected depending upon the temperature profile, throughput rate and initiator levels. More preferred residence times are in the range of from 15 seconds to 120 seconds.

10

Vacuum venting can be applied to remove volatile by-products, solvents and excess monomer.

While not wishing to be limited by theory, it is believed that the effectiveness of benzoyl
15 peroxide and t-butyl perbenzoate in the present invention is determined by three factors:

(a) The rate and specificity of the reaction of benzoyloxy or the derived phenyl radicals with polypropylene and the monomer. These radicals show less specificity for abstraction of tertiary vs. primary or secondary hydrogens than do, for example, alkoxy or alkyl
20 radicals.

(b) The initiator half-life. Use of an initiator with a short initiator half-life will generate a locally high concentration of radicals thus increasing the likelihood of radical combination events.

25

(c) The solubility characteristics of the initiator in the polymer melt.

Similarly, it is believed that the effectiveness of the styrene as a monomer is determined by:

30

(a) The solubility of the monomer in the polymer melt. Styrene is known to be soluble in molten polypropylene.

(b) The reactivity of the monomer towards polypropylene derived radicals.

5

(c) The propensity for the radical formed by addition of monomer to give combination or addition (which leads to branch or crosslink formation) vs. disproportionation or hydrogen abstraction. It is known that the benzylic radicals give predominantly combination and have low (with relation to other radicals) tendency to abstract hydrogen.

10

Other initiators and monomers that meet the above criteria may also be used to advantage in the present invention.

Surprisingly, the process of the present invention results in a polypropylene (co)polymer
15 with substantially increased melt strength. We have found that it is possible with the present invention to obtain a polypropylene (co)polymer which has a melt strength at least 25% greater than the melt strength of the base polymer. We have also found that it is possible to obtain an increase in melt strength of greater than 100% for a number of the polypropylene (co)polymers produced in accordance with the process of the present
20 invention. Increases in melt strength were assessed using a Gottfert-Rheotens melt strength tester operated with a roller acceleration of 1.2 cm/sec^2 measuring the melt strength of a 2 mm strand of molten polypropylene (co)polymer (melt temperature of 210°C) which is fed to the Gottfert tester at $\sim 4 \text{ g/min}$.

25 In a further aspect of the present invention there is provided a modified polypropylene (co)polymer produced according to the process described herein, wherein said modified polypropylene (co)polymer preferably has a melt strength at least 25%, and more preferably at least 100%, greater than the unmodified polypropylene (co)polymer.

The polypropylene (co)polymers produced according to the process of the present invention also may provide a significant increase in long-chain branching. Long-chain branching may be assessed by the Dow Rheology Index. Advantageously, the modified polypropylene (co)polymers may demonstrate a Dow Rheology Index (DRI) of greater
5 than 1, preferably at least 2 and most preferably greater than 50.

The process of the present invention may also be used to increase the melt elasticity of a polypropylene (co)polymer.

10 Advantageously, the process of the present invention also provides a means to alter the molecular weight, molecular weight distribution and/or degree and length of branching of polypropylene, ethylene-propylene copolymers, and analogous α -olefin copolymers with or without altering the melt strength of said polymers by melt processing.

15 The process of the present invention may provide a means to generally increase the molecular weight and broaden the molecular weight distribution and/or introduce branching of the polypropylene (co)polymer. This will not always equate to significant increases in the melt strength or extensional viscosity of the polymer that is being modified eg modification of a lower molecular weight polymer to broaden the molecular
20 weight and/or induce shorter branches. Such a product may not necessarily demonstrate a high melt strength, but may demonstrate other desirable properties, for example improved filler uptake, mechanical properties, thermal and morphological properties.

The modified polypropylene (co)polymer produced by the process of the present invention
25 may be used either neat or blended with another polymer or other additives to provide the desired balance of properties in the polymer blend.

The modified polypropylene (co)polymers and blends may be used in a wide variety of applications including thermoforming, blow moulding, tube or pipe extrusion, blown
30 films, foams.

The present invention may also be used in the recycling of waste polypropylene or materials containing waste polypropylene.

5 The increased melt strength of the modified polypropylene (co)polymers renders these (co)polymers more suitable for use in thermoforming applications. The modified polypropylene (co)polymers may be used to thermoform containers such as margarine tubs. The benefits of this invention include that the polypropylene (co)polymers and blends containing same provide a wider processing window than conventional isotactic
10 polypropylene. The modified polypropylene (co)polymers may also be used in large part thermoforming such as in the production of refrigerator liners and the like where conventional isotactic polypropylene is unsuitable.

The modified polypropylene (co)polymers produced in accordance with the present
15 invention are suitable for blow moulding and we have found that they can be more readily blow moulded into containers. Furthermore, the increased melt strength makes it possible to produce large blow moulded parts through the use of the high melt strength modified polypropylene (co)polymer. Thus components currently made by rotational moulding may now be produced by blow moulding using the modified polypropylene (co)polymer of the
20 present invention.

Profile extrusion for example tube or pipe extrusion, using the modified polypropylene (co)polymer has been found to produce a more consistent product than conventional isotactic polypropylene.

25

Blown films made of polypropylene are generally blown downwards using relatively expensive equipment. The modified polypropylene (co)polymers of the present invention have sufficient melt strength for them to be able them to be blown upwardly using conventional polyethylene type film blowing equipment which is less expensive and

generally more convenient to operate. Advantageously the modified polypropylene (co)polymers of the present invention may be used in the production of blown films.

The modified polypropylene (co)polymers of the present invention may also be foamed
5 with a wider processing window than for conventional polypropylene. Either a physical or chemical blowing agent may be used. It is preferred to use carbon dioxide as a physical blowing agent to produce foams having a fine closed cell structure. Foamed pellets may be subsequently moulded to form components for use in a variety of applications such as automotive door trims, rooflinings, dash boards, bumpers and the
10 like. Applications such as in foamed packaging are also possible, including thermoformed containers, insulating cups and the like.

Waste polypropylene or waste streams containing a significant proportion of polypropylene are presently difficult to recycle as conventionally a high degree of chain
15 scission results from the recycling process. The process of the present invention may be used to upgrade recycled streams containing polypropylene by increasing the overall mechanical properties of the recycled polypropylene by the addition of initiator and monomer in accordance with the present invention.

20 The present invention will now be described with reference to the following non-limiting examples. Described hereunder are the measurement techniques used in the examples and a full description of the process conditions employed. Comparative Examples are labelled CE-n.

25 Melt Strength Measurement

Melt strengths were measured on a "Rheotens" Melt Strength Tester, Type 010.1, supplied by Gottfert Werkstoff-Prufmaschinen GmbH of Buchen, Germany. This test involves drawing an extruded strand of polymer vertically into the nip between two
30 counter-rotating nip rollers. The strand was extended using a Brabender Plasticord single

screw extruder of screw diameter 19mm and length to diameter ratio (L/D) of 25. The extrudate exited via a right angle capillary die (2mm diameter). The temperature profile used was uniform along the length of the barrel of the extruder and the die and was set at 190°C. The nip rollers are mounted on a balance arm which allows the force in the
5 drawing strand to be measured. The velocity of the nip rolls is increased at a uniform acceleration rate. As the test proceeds, the force increases until eventually the strand breaks. The force at breakage is termed the "melt strength".

While there is no internationally-established standard set of test requirements for melt
10 strength testing, comparative melt strength values obtained under the given set of test conditions provide a quantitative determination of the increase in melt strength used in the patent. The test conditions used were: die temperature 190°C, extruder output rate ~4 g/min, acceleration rate 1.2 cm/sec², draw distance 210 mm, matt finish steel rollers.

15 Dow Rheology Index

The Dow Rheology Index (DRI) is believed in the art to be a measure of the long chain branching in a polymer. It is expressed as the deviation of a viscosity parameter obtained from shear rheology measurements on a "branched" polymer compared with that for a
20 linear polymer. The branched polymers have lower values of the viscosity parameter than the linear polymers (for a given relaxation parameter). The parameters are obtained by fitting the Cross model to the shear viscosity flow curves. The DRI method has been described by Lai, Plumley, Butler, Knight and Kao in a paper in SPE ANTEC '94 Conference Proceedings (pp1814-1818) - "Dow Rheology Index (DRI) for Insite
25 Technology Polyolefins (ITP): Unique Structure-Processing Relationships".

Dynamic Rheology Tests

The dynamic rheology tests were performed on a Rheometrics Dynamic Stress Rheometer
30 SR200. Test conditions were: parallel plates, temperature 190°C, frequency range 0.01

to 100 rad/sec, and 3-4% strain, in a nitrogen atmosphere to prevent degradation. G' is the storage modulus representing the elasticity of the polymer melt, G'' is the loss modulus which represents the viscous component of the deformation. The polydispersity index is 10 to power 5 divided by the crossover modulus, which is the value of $G' = G''$

5 when the G' and G'' curves crossover - it is believed to be a measure of MWD. The higher G' , the greater elasticity in the polymer and the higher the MW.

MFI

10 Melt flow indexes (MFI) were measured at 230°C with a 2.16 kg load according to ASTM 1238.

Drop Times

15 The drop times were determined by measuring the time taken for the polypropylene strand (cut at the die face) to drop from the die of the extruder to the floor. The die of the JSW twin screw extruder was 1140 mm above the floor. The drop time test combines the effects of melt viscosity, extensional viscosity, chain entanglement (as shown by die swell), and elasticity (as shown by the tendency resist neck formation). Higher melt
20 viscosity polypropylene polymers had drop times which incorporated some additional effect due to prolonged cooling of the slower moving (falling) molten strand.

GPC

25 GPC molecular weights were determined using a Waters 150C high temperature GPC unit. 1,2,4-trichlorobenzene was used as the solvent, eluting through two Styragel HT6E linear columns. The oven temperature was set at 140°C and the pump flow rate was 1.0ml/min.

Calibration was performed using narrow polydispersity polystyrene standards. All molecular weights quoted as polystyrene equivalents.

Mn = number average molecular weight

Mw = weight average molecular weight

5 Mz = viscosity average molecular weight

Mp = peak molecular weight

Twin Screw Extruder

- 10 The twin screw extruder used in the examples was a JSW TEX-30 with a 30 mm screw diameter and an overall L/D of 42 [comprising ten temperature controlled barrel sections (L/D 3.5, temperatures between 120 and 230°C as specified in Table 1), three unheated sampling/monitoring blocks (L/D 1.167) and a cooled feed block (L/D 3.5)] equipped with two JSW TTF20 gravimetric feeders, one K-Tron KQx gravimetric additives feeder
- 15 and a volumetric liquid addition pump (Fuji Techno Industries model HYM-03-08)]. The extruder was operated in either co-rotating (intermeshing self wiping) or counter rotating (intermeshing non-self wiping) modes with a throughput rate of between 5 and 20 kg/hr and screw speeds of between 100 and 400 rpm as specified in Table 1. The melt temperature and pressures were monitored at three points along the barrel and in the die.

Table 1 Operating conditions

Conditions	Screw Speed (rpm)	Feed Rate (kg/hr)	Temperature Profile (°C)
A	265	20	150°C, 175°C (by 10)
B	265	20	180°C, 200°C (by 3), 220°C (by 7)
C	150	5	120°C, 130°C (by 4), 180°C (by 6)
D	265	20	140°C, 150°C (by 10)
E	265	20	180°C, 200°C (by 4), 230°C, 240°C, 250°C, 260°C, 270°C, 280°C.
F	400	20	180°C, 220°C (by 10)
G	265	20	80°C, 120°C, 140°C, 160°C, 170°C, 180°C, 200°C (by 5)
H	150	5	80°C, 120°C, 140°C, 160°C, 170°C, 180°C, 190°C (by 3), 200°C (by 2)
I	265	20	80°C, 120°C, 140°C, 160°C, 170°C, 180°C, 190°C (by 3), 200°C (by 2)

- The temperatures in the table refer to sections of the barrel of the extruder that are capable of independent temperature control. The first ten temperatures are barrel section temperatures and the last temperature indicates the temperature of the die.

Table 2 - Die configuration

Condition	Die Description
1	Large 3 hole strand die - 6 mm holes
2	Small 3 hole strand die - 4 mm holes
3	Large 2 hole strand die - 6 mm holes
4	Single hole Brabender die- 10mm hole

Table 3 - Means of modifier addition

Condition	Die Description
α	Modifier added at block 4 in 2-butanone carrier solvent
β	Modifier added at block 4 in xylene carrier solvent
γ	Modifier coated onto PP powder - pre tumble blended
δ	Modifier coated onto PP powder masterbatch

- 5 The overall extruder configuration may be recited, for example, as condition: A1 δ .

Solvent Addition of Modifiers

The initiator was introduced as a solution in 2-butanone or xylene. The concentration of
10 the initiator varied from 5.6% wt/wt to 8.5% wt/wt. The benzoyl peroxide was a powder wetted with 25% (wt/wt) water. t-Butyl peroxybenzoate is a liquid.

Increased levels of initiator were generally added by increasing the amount of solution added to the polymer melt. The additional peroxides (if any) were added with the initiator
15 in the carrier solvent.

Solid Addition of Modifiers

For the solventless modification of the polymer the initiator was generally absorbed onto
20 or blended with powdered polymer at concentrations ranging from 5% wt/wt to 10%

wt/wt to form a masterbatch. The masterbatch was added to the extruder in varying feed rates to alter the amount of additives. The amount of polymer feed was adjusted accordingly to give constant overall feed rate.

- 5 The stabilisers were also added as a masterbatch. The amount of stabiliser was generally kept constant at 0.33%wt/wt Irganox 1010 and 0.17%wt/wt Irgaphos 168 in the total composition.

The main polymer feed was added as either powder or pellets.

10

Single Screw Extruder

The single screw extruder used in the examples was a Killion segmented single screw extruder of L/D=40 (11 barrel sections , 10 heated) and screw diameter of 31.75 mm.

15

Polypropylene powder, stabilisers (0.33%wt/wt Irganox 1010, 0.17%wt/wt Irgaphos 168 in total) and initiator were added to the feed throat of the single screw extruder via a twin screw K-Tron volumetric feeder.

- 20 Alternatively, the polypropylene powder and stabilisers were added via the K-Tron feeder and polypropylene powder, stabilisers and the modifiers were added as a master batch via a single screw APV Accurate volumetric feeder. The masterbatch contained 7.5%wt/wt benzoyl peroxide (prepared using a dispersion of benzoyl peroxide containing 25%wt/wt water).

25

The output of the extruder was ~1.5 kg/hr using a screw speed of 30rpm. The set barrel temperature was either (i) a flat 220°C with each barrel section and the die set at a temperature of 220°C or (ii) 230°C/190°C with the first six melting sections of the barrel set at 230°C and the next four metering sections of the barrel and the die set at 190°C.

- 30 The melt temperature varied from 220 to 260°C.

The following commercial polypropylene (co)polymers were used in the examples. The properties of the (co)polymers are shown in Table 4 below.

5 Table 4: Comparative data for a grade of high melt strength PP and conventional PP grades.

Example	Polymer	Polymer Description	MFI 2.16kg @ 230°C	Melt Strength cN
Control 1	Montell PF814	High melt strength polypropylene homopolymer	3	18
Control 2	Montell JE6100	Extrusion grade polypropylene homopolymer	3	3
Control 3	ICI Australia GYM 45	Injection moulding grade of polypropylene homopolymer	14	1.8
Control 4	ICI Australia GWM 22	Extrusion grade of polypropylene homopolymer	4	2.8
Control 5	ICI Australia PXCA 6152	Thermoforming grade of polypropylene homopolymer	0.8	6
Control 6	ICI Australia LYM 120	Injection moulding grade of propylene/ethylene copolymer	14	1.4
Control 7	Montell 6501	Ex-reactor grade of injection moulding polypropylene homopolymer	4.1	~3

* Melt strength and MFI were measured for a particular batch and we have found actual values vary up to 20% of these values.

Examples 1

GYM45 was modified in accordance with Table 5 below. GYM45 is a low molecular weight/higher MFI injection moulding grade of polypropylene homopolymer.

5

Table 5: Effect of addition of BPO with styrene in 2-butanone upon modification of GYM45.

Example	Conditions	BPO (wt%)	Styrene (wt%)	Motor Current (amps)	Die Temp. (°C)	Drop Time (secs.)	MFI 2.16kg @ 230°C	Melt Strength (cN)
CE 1	B1α	0	0	13	231	8	12.2	1.5
1	D4α	0.34	0.45	21	179	22.9	9.1	6.9

Example 1 shows a significant increase in the melt strength (better than tripled) for low level addition of BPO and styrene (1:1.3 wt/wt).

Examples 2 to 10

GWM22 was modified in accordance with Table 6. GWM22 is an intermediate molecular weight/medium MFI extrusion grade of polypropylene homopolymer.

Table 6: Effect of addition of BPO with styrene in 2-butanone upon the modification of GWM22

Example	Conditions	BPO (wt%)	Styrene (wt%)	Motor Current (amps)	Die Temp. (°C)	Drop Time (secs.)	MFI 2.16kg @ 230°C	Melt Strength (cN)
Control 4							4.5	2.8
CE 2	B1α	0	0	16	239	11.3	5	-
2	B1α	0.12	0.16	16	237	8.0	4.15	-
3	B1α	0.23	0.31	17	237	11.2	2.8	5
4	B1α	0.46	0.61	21	238	14	1.11	-
5	B1α	0.69	0.92	21	241	14.2	0.69	18.6
6	B1α	1.22	1.63	21	248	-	-	18.6
7	E1α	0.33	0.44	17	281	20	3.6	8.2
8	C2α	0.81	4.2	18	203	60	0.69	18.8
9	E1α	0.31	0.40	20	275	23	3.1	7.0
10	E1α	0.30	0.53	17	277	24	3.4	9.1

5 Examples 3 and 5 show a significant increase in the melt strength with an increase in BPO and styrene. There is also generally an increase in the drop time.

The melt strength of GWM22 increases more than six fold as a result of the addition of less than 0.7 %wt/wt BPO and 0.9 %wt/wt styrene.

10

Example 7 shows that an overall increase in melt strength and decrease in MFI is gained through modification even at high extrusion temperatures (280°C) where chain scission is normally expected to be the dominant reaction in the processing of unmodified PP homopolymer.

The increase in complex viscosity of examples 6,8,9 and 10 is shown in Figure 1. The comparison with control sample 4 shows that the molecular weight of the samples has been increased, quite markedly for samples 6 and 8. Also the shape of the graphs (less curved for the modified grades compared with the control samples) indicates that the molecular structure has been altered (greater MWD and/or branching) G' has been plotted against frequency in Figure 2.

The modified polypropylene's of examples 6,8,9 and 10 were tested for additional physical properties and it was found that the modified polypropylene's had:

	6	8	9	10	Control 4	
i) Elasticity rad/s (Pa)	1200	680	40	45	10	G'@ 0.01 rad/s (pa)
ii) 1/Relaxation Time	~0.0013	0.085	15	18	23	Crossover Frequency(rad/sec)
iii) Polydispersity Index	222	39	4.4	4.7	3.7	M _w /M _n
iv) Dow Rheology Index	192	86	2.0	5.6	0	LongChain Branching

The DRI of the modified polypropylene's demonstrates a significant degree of long chain branching.

15 Examples 11 to 14

PXCA6152 was modified in accordance with Table 7 below. PXCA6152 is a high molecular weight/low MFI thermoforming grade of polypropylene homopolymer.

Table 7: Effect of addition of BPO with styrene in 2-butanone upon the modification of PXCA6152

Example	Conditions	BPO (wt%)	Styrene (wt%)	Motor Current (amps)	Die Temp. (°C)	Drop Time (secs.)	MFI 2.16kg @ 230°C	Melt Strength (cN)
Control 5							0.8	6
Ce 3	F1α	0	0	17	251	14.6	1.1	-
11	F1α	0.31	0.41	21	256	24.4	0.42	17.5
12	F1α	0.47	0.63	21	264	25	0.31	-
13	F1α	0.55	0.73	23	269	-	0.40	-
14	F1α	0.71	0.95	22	259	25	0.35	21.3

5

Examples 11, 12 and 14 show that the additives produce a decrease in MFI and an increase in drop times. The results show a significant increase in the melt strength.

Examples 15 to 19

10

LYM120 was modified in accordance with Table 8 below. LYM120 is a low molecular weight/higher MFI injection moulding grade of PP copolymer.

Table 8: Effect of addition of BPO with styrene in 2-butanone upon the modification of LYM120.

Example	Conditions	BPO (wt%)	Styrene (wt%)	Motor Current (amps)	Die Temp. (°C)	Drop Time (secs.)	MFI 2.16kg @ 230°C	Melt Strength (cN)
Control 6							12.2	1.4
15	A2 α	0.33	0.44	18	202	28	5.8	7.4
16	D2 α	0.32	0.42	23	185	46.5	3.8	9.0
17	A4 α	0.42	0.55	19.5	204	31.1	6.5	11.2
18	A4 α	0.62	0.83	20	201	36.8	-	11.9
19	A4 β	0.34	0.45	16	199	25.1	-	4.3

Examples 15, 17 and 18 shows an increase in melt strength with increasing level of 5 BPO/styrene.

Examples 20 to 27

Ex-reactor GYM45 powder was modified according to Table 9 below. GYM45 is a low molecular weight/higher MFI injection moulding grade of polypropylene homopolymer.

Table 9: Effect of a feed throat addition of BPO with styrene to ex-reactor GYM45 powder

Example	Conditions	BPO (wt%)	Styrene (wt%)	Motor Current (amps)	Die Temp. (°C)	Drop Time (secs.)	MFI 2.16kg @ 230°C	Melt Strength (cN)
CE 4	H38	0	0	7	209	21.5	11.3	1.7
20	I38	0.15	0.2	18	215	16.6	9.6	2.0
21	I38	0.23	0.3	16	214	20.5	6.5	5.5

Example 21 shows the melt strength can be increased three fold by using low levels of BPO and styrene.

5 Examples 22 to 28

GYM45 was modified in accordance with Table 10 below. GYM45 is a low molecular weight/higher MFI injection moulding grade of polypropylene homopolymer.

10 Table 10 Effect of addition of various peroxides with styrene in 2-butanone upon the modification of GYM 45.

Example	Conditions	Initiator	Initiator (wt%)	Styrene (wt%)	Motor Current (amps)	Die Temp. (°C)	Drop Time (secs)	MFI 2.16kg @ 230°C
CE 5	A3α	-	0	0	18	192	11.8	12.8
22	A3α	BPO	0.12	0.16	16	197	14	14.4
23	A3α	BPO	0.21	0.28	17	200	18.8	9.8
24	A3α	BPO	0.41	0.55	20	206	27.6	5.6
25	A3α	BPO	0.62	0.83	22	208	32.2	3.6
CE-6	A3α	DHBP	0.33	0.09	14.5	191	4.6	55.
CE-7	A3α	DHBP	0.60	0.17	16	190	4	117
CE-8	A3α	DHBP	0.90	0.28	14.5	190	3.9	132
CE-9	A3α	TBEH	0.33	0.34	16	191	9.9	18.3
CE-10	A3α	TBEH	0.60	0.62	17	192	10	19.5
CE-11	A3α	TBEH	0.90	0.93	17	193	10.6	17.2
26	A3α	TBPB	0.30	0.30	15	194	7.8	58.3
27	A3α	TBPB	0.68	0.70	17	198	14	47.3
28	A3α	TBPB	0.89	0.91	19	199	15.6	38.5
CE-12	A3α	DCP	0.08	0.09	14.5	192	4.3	48.5
CE-13	A3α	DCP	0.17	0.17	15	191	3.9	64.7
CE-14	A3α	DCP	0.25	0.25	15	191	3.7	90.3
CE-15	A3α	DLP	0.33	0.33	15	190	11.2	16.5
CE-16	A3α	DLP	0.63	0.64	15	190	11.1	15.1
CE-17	A3α	DLP	0.92	0.93	15	190	11.1	18.0

Examples 22 to 28 show an increase in drop time and generally a decrease in MFI with increasing levels of BPO or TBPB, whereas for the other peroxides the drop time

decreases and the MFI increases. The high MFI values indicate a very high degree of chain scission.

Examples 29 to 35

5

LYM120 was modified in accordance with Table 11 below. LYM120 is a low molecular weight/higher MFI injection moulding grade of polypropylene copolymer.

Table 11: Effect of addition of various peroxides with styrene in 2-butanone upon the modification of LYM120.

Example	Conditions	Initiator	Initiator (wt %)	Styrene (wt %)	Motor Current (amps)	Die Temp. (°C)	Drop Time (secs)	MFI 2.16kg @ 230°C	Melt Strength (cN)
CE-18	A3 α	BPO	0.00	0.00	16	195	9.9	12.8	1.1
29	A3 α	BPO	0.12	0.16	15	197	13.9	10.9	
30	A3 α	BPO	0.21	0.28	17.5	201	17.7	7.50	
31	A3 α	BPO	0.41	0.55	20	208	25.8	4.4	11.5
32	A3 α	BPO	0.62	0.83	21	209	26.5	2.9	
CE-19	A3 α	DHBP	0.08	0.09	13.5	191	4.9	52	
CE-20	A3 α	DHBP	0.16	0.17	14	190	5.3	79	
CE-21	A3 α	DHBP	0.28	0.30	14.5	190	5.6	114	
CE-22	A3 α	TBEH	0.31	0.32	14	192	8.6	17.8	
CE-23	A3 α	TBEH	0.62	0.64	14	192	9	17.4	
CE-24	A3 α	TBEH	0.98	1.01	14	192	9.6	15.4	
33	A3 α	TBPB	0.30	0.31	14	196	4.6	33.8	
34	A3 α	TBPB	0.61	0.62	17	200	14.6	32.9	
35	A3 α	TBPB	0.93	0.95	17	202	15.6	23.1	
CE-25	A3 α	DCP	0.08	0.09	13	192	5	38.6	
CE-26	A3 α	DCP	0.17	0.17	13.5	190	5.5	57.6	
CE-27	A3 α	DCP	0.27	0.28	14	190	6.2	65.9	
CE-28	A3 α	DLP	0.31	0.31	15	191	9.9	15.7	
CE-29	A3 α	DLP	0.64	0.65	13.5	190	9.8	14.8	
CE-30	A3 α	DLP	1.00	1.01	13	190		14.8	

Examples 29 to 35 show an increase in drop time and a decrease in MFI with increasing levels of BPO or TBPB. For the other peroxides the drop time decreases and the MFI increases. The high MFI values indicate a very high degree of chain scission.

5 Examples 35 to 41

LYM120 was modified in accordance with Table 13 below. LYM120 is a low molecular weight/higher MFI injection moulding grade of polypropylene copolymer.

10 Table 13: Effect of feed throat addition of various peroxides with styrene to ex-reactor LYM120 powder.

Example	Conditions	Initiator	Initiator (wt%)	Styrene (wt%)	Motor Current (amps)	Die Temp. (°C)	Drop Time (secs)	MFI 2.16kg @ 230°C	Melt Strength (cN)
CE-31	A38	-	0		14.5	200	10	12.4	1.1
35	A38	BPO	0.11	0.15	17.5	205	19.1	5.7	2.4
36	A38	BPO	0.23	0.30	19.5	210	25	4.3	6.3
37	A38	BPO	0.45	0.6	21.5	209	27.8	2.1	10.4
38	A38	BPO	0.90	1.2	23.5	210	26.8	1.3	12.2
CE-32	A38	DLP	0.30	0.3	14.5	199	9.4	14.1	-
CE-33	A38	DLP	0.59	0.6	13	197	9.3	17.2	-
CE-34	A38	DLP	0.89	0.9	13	197	9.8	16.1	-
39	A38	TBPB	0.29	0.3	13.5	196	11.4	20.4	3.7
40	A38	TBPB	0.59	0.6	16.5	200	20.2	12.9	-
41	A38	TBPB	1.18	1.2	17	202	18.8	13.9	4.5

Examples 35 to 41 show that the melt strength of LYM120 PP ex-reactor powder increases with the addition of increasing levels of BPO or TBPB. BPO is more effective for a given concentration than TBPB.

5 Examples 42 to 57

LYM120 was modified in accordance with Table 14 below. LYM120 is a low molecular weight/higher MFI injection moulding grade of polypropylene copolymer.

10 Table 14: Effect of peroxide to styrene ratio and the addition of various peroxides with styrene in 2-butanone upon the modification of LYM120.

Example	Conditions	Initiator	Initiator (wt %)	Styrene (wt %)	Mole Ratio Sty/Init	Motor Current (amps)	Die Temp. (°C)	Drop Time (secs)	MFI 2.16kg @ 230°C	Melt Strength (cN)
CE-35	A3α	0	0	0	-	16	195	9.9	12.8	1.1
42	A3α	BPO	0.43	0.19	1.04	16	207	18.5	6.9	-
43	A3α	BPO	0.41	0.37	2.07	19	207	22.5	4.9	-
44	A3α	BPO	0.41	0.55	3.11	20	208	25.8	4.4	11.6
45	A3α	BPO	0.43	0.76	4.14	21	210	25.4	3.9	-
46	A3α	BPO	0.45	0.99	5.18	20	205	28.3	4.4	-
47	A3α	TBPB	0.56	0.19	0.78	13	192	8.9	71	-
48	A3α	TBPB	0.55	0.37	1.57	14	196	11.0	38	-
49	A3α	TBPB	0.61	0.62	1.91	17	200	14.6	33	-
50	A3α	TBPB	0.54	0.73	3.14	16	201	16.0	19.2	-
51	A3α	TBPB	0.58	0.97	3.92	19	204	16.2	15.7	-
CE-36	A3α	DHBP	0.27	0.1	0.84	13	190	4.4	187	-
CE-37	A3α	DHBP	0.25	0.18	1.69	14	191	5.3	125	-
CE-38	A3α	DHBP	0.28	0.30	3.04	14.5	190	5.6	114	-
CE-39	A3α	DHBP	0.27	0.40	3.38	15	193	6.2	116	-
CE-40	A3α	DHBP	0.28	0.50	4.22	14	192	6.1	118	-

Examples 52 to 56

GYM45 was modified in accordance with Table 15 below. GYM45 is a low molecular weight/higher MFI injection moulding grade of polypropylene homopolymer.

5

Table 15 Effect of the molar ratio of BPO to styrene in 2-butanone upon the modification of GYM 45.

Example	Conditions	Initiator	Initiator (wt%)	Styrene (wt%)	Mole Ratio Sty/Init	Motor Current (amps)	Die Temp (°C)	Drop Time (secs)	MFI 2.16kg @ 230°C
CE-41	A3α	-	0.00	0.00	0.00	18	192	11.8	12.75
52	A3α	BPO	0.36	0.16	1.04	18	202	18.1	11.17
53	A3α	BPO	0.41	0.37	2.07	18	209	23.5	6.38
54	A3α	BPO	0.41	0.55	3.11	20	206	27.6	5.62
55	A3α	BPO	0.43	0.76	4.14	22	209	25.7	4.05
56	A3α	BPO	0.40	0.89	5.18	21	207	31.2	4.27

Examples 57 to 64

10

LYM120 was modified in accordance with Table 16 below. LYM120 is a low molecular weight/higher MFI injection moulding grade of polypropylene copolymer.

Table 16: Effect of an additional initiator on the feed throat modification of BPO and styrene to ex-reactor LYM120 powder.

Example	Conditions	Initiator #1 wt %	Initiator #2 wt %	Mole ratio Init#1/ Init#2	Monomer wt %	Mole Ratio Monomer / tot init	Motor Current (amps)	Drop time secs	Die Temp °C	MFI	Melt Str. (cN)
Initiator#1=BPO, Initiator#2=DHBP, Monomer = Styrene											
57	A38	0.43	0.06	9.08	0.57	2.81	19	17	204	6.9	3.8
58	A38	0.43	0.11	4.54	0.58	2.57	19	14.8	203	10.5	2.9
59	A38	0.43	0.17	3.03	0.58	2.37	18	14	201	16.9	-
Initiator#1=BPO, Initiator#2=TBPB, Monomer = Styrene											
60	A38	0.43	0.11	3.07	0.58	2.36	20	18.7	208	5	5.5
61	A38	0.43	0.22	1.53	0.58	1.92	17	14.2	204	9.3	4.2
62	A38	0.43	0.34	1.02	0.59	1.62	18	14	204	11.6	-
63	A38	0.43	0.45	0.77	0.60	1.40	18	11.8	201	19.5	-
64	A38	0.43	0.34	1.02	0.94	2.59	21	17	207	7.5	6.3

- 5 Addition of the second initiator allows the increased melt strength to be obtained while retaining relatively high MFI.

Examples 65 and 66

- 10 Montell 6501 was modified in accordance with Table 17 below on the Killion single screw extruder described above.

Table 17: Effect of feed throat addition of BPO with styrene to Montell 6501 ex-reactor powder using the Killion SSE.

Sample	Barrel Temp. (°C)	Extruder Output (kg/hr)	BPO wt%	Styrene wt%	Motor Current (amps)	Die Temp. (°C)	Drop Time (secs.)	MFI (g/10 min.)
Control 7	-	-	-	-	-	-	-	4.1
CE 42	220 flat	1.4	0	0	6	256	17	4.1
65	220 flat	1.4	2.1	0.25	6	260	35	2.2
66	220 flat	1.4	4.2	0.5	7.5	263	33	0.40

Table 18: GPC molecular weights for various modified PPs.

Example No.	Cond.	BPO (wt %)	Sty. (wt %)	MFI (g/10 min)	Melt Str. (cN)	Mn (g/mol) $\times 10^{-3}$	Mw (g/mol) $\times 10^{-3}$	Mz (g/mol) $\times 10^{-3}$	Mp (g/mol) $\times 10^{-3}$
Intermediate Molecular Weight PP Homopolymer (GWM 22)									
Control	-	-	-	4.5	2.8	55	295	1200	105
4									
17	B1 α	0.12	0.16	4.15	-	90	405	1200	235
18	B1 α	0.23	0.31	2.80	5.0	75	415	1400	195
19	B1 α	0.46	0.61	1.11	-	70	555	2200	205
20	B1 α	0.69	0.92	0.69	18.6	85	575	2200	180
-	C1 α	0.37	0.49	2.22	-	85	565	2035	215
-	C1 α	0.60	0.80	1.00	19.4	85	690	2575	170
-	C1 α	0.32	1.65	4.50	-	80	505	1835	170
-	C1 α	0.47	2.45	1.58	-	90	605	2160	205
-	C1 α	0.81	4.19	0.69	18.8	85	675	2610	185
Low Molecular Weight PP Copolymer (PXCA 6152)									
Control	-	-	-	12.4	1.4	45	230	720	130
5									
27	A2 α	0.33	0.44	-	7.4	65	325	1045	140
61	A2 α	0.41	0.55	4.4	11.5	60	325	1315	125
62	A2 α	0.62	0.83	2.9	-	70	460	2435	135
-	D2 α	0.28	0.38	-	-	80	555	2875	160
28	D2 α	0.32	0.44	-	9.0	120	640	4130	140

* Errors in the molecular weight are generally less than 30% of the quoted value, as is usual in high temperature GPC under the conditions employed.

Examples of Carbon Dioxide Foaming of Modified PP.

The equipment used for foaming the polypropylene (from the earlier examples) was a tandem extrusion line made up of an Leistritz twin screw extruder (34 mm screw diameter, co-rotating, with 11 barrel sections) connected via a melt pipe to a single screw extruder (43 mm screw diameter,). CO₂ was introduced into barrel six of the twin screw extruder. The gassed polymer was then cooled slowly in the single screw extruder.

Example	MFI (g/10 min.)	Melt Strength (cN)	Foaming - Temp. (°C)	Av. Foam Density (g/cc)	Av. Cell Size (um)
Control 1	3	18	166 to 159	0.058	550
13	0.4	-	169 to 159	0.044	300
17	6.5	11.2	167 to 161	0.051	280

- 10 Non high melt strength grades of polypropylene have foam temperature processing windows of less than 1°C.

Foamed examples 13 and 17 both had a fine closed cell structure.

15 Examples of thermoforming

The modified polypropylene produced in Example 37 was extruded on a Welex single screw extruder through a sheet die to produce a sheet 78 cm wide and ~1.25 mm thick. The sheet was fed to a Gabler F702 continuous thermoformer to produce margarine tubs.

Tubs produced from the modified PP sample had a crush strength of 25 kg after 1 hour. No appreciable sag was noticed of the PP sheet during the process.

Blow Moulding

5

The modified polypropylene of Example 1 was blow moulded on Bekum blow moulder fitted with a general purpose polyolefin screw using a 750 ml screw top bottle mould, (radially non symmetrical bottle with waist). The mould temperature was 0°C.

- 10 The blow mouldability of the modified injection moulding grade of PP was compared against that of a commercial low melt flow index PP homopolymer (ICI GWM110 of MFI = 1.5).

15 It was found that the modified PP homopolymer (MFI = 9.1 and Melt Strength = 6.9 cN) could be easily blow moulded into 750 ml bottles. Conventional PP of similar MFI could not be successfully blow moulded. The modified PP gave similar performance to an extrusion grade PP of low MFI.

The results are very promising where a higher MFI PP could be used to blow bottles.

20 This possibly opens up the opportunity to produce large blow moulded parts through use of a high melt strength modified PP which has been tailored to have an MFI acceptable to blow moulding (ie 1-2 MFI)

Those skilled in the art will appreciate that the invention described herein is susceptible to variations and modifications other than those specifically described. It is to be understood that the invention includes all such variations and modifications which fall within its spirit
5 and scope. The invention also includes all of the steps, features, compositions and compounds referred to or indicated in this specification, individually or collectively, and any and all combinations of any two or more of said steps or features.

DATED this 19th Day of JANUARY 1998 -

10

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15

FIGURE 1

COMPLEX VISCOSITY vs. FREQUENCY for MODIFIED POLYPROPYLENES
at 190 degC

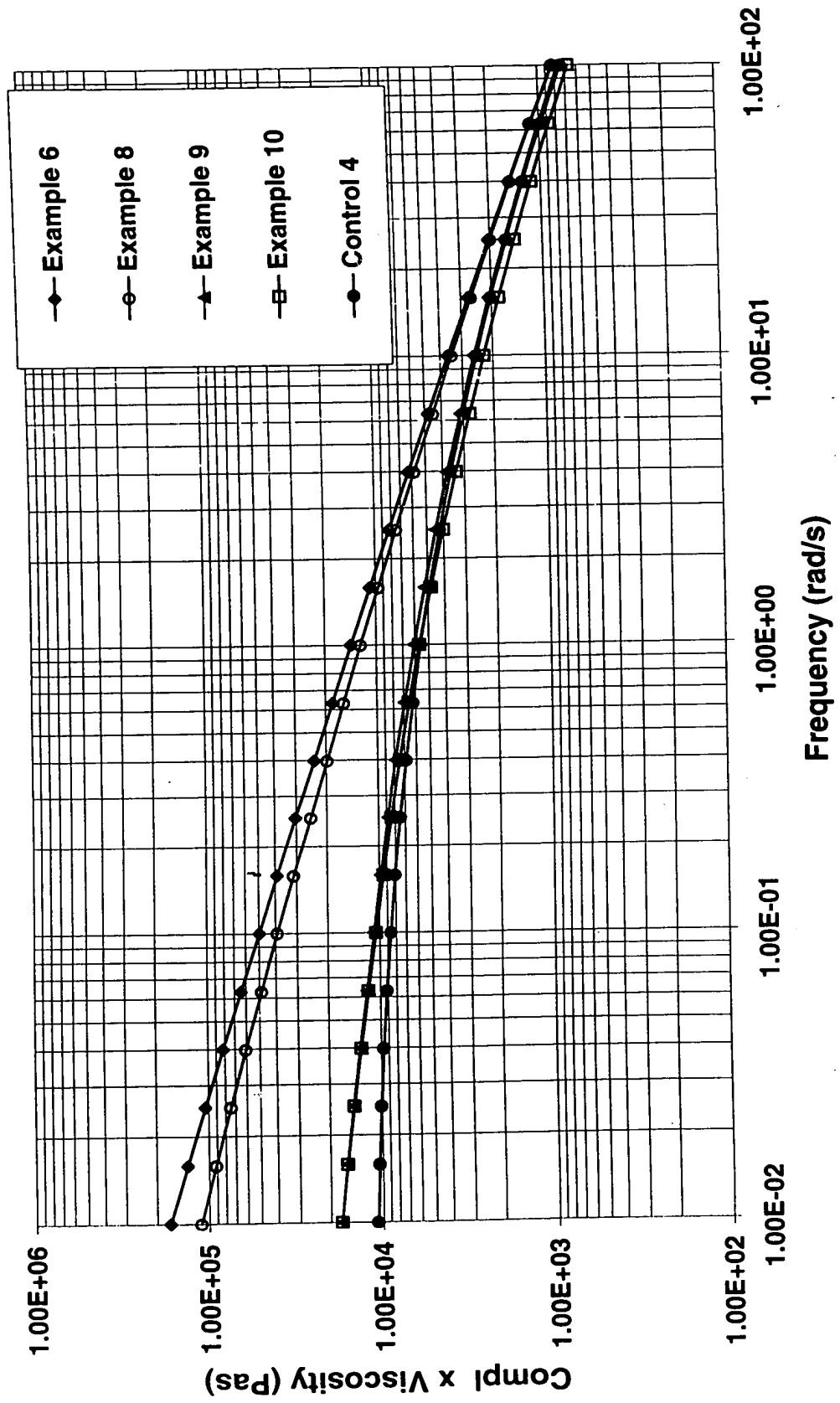
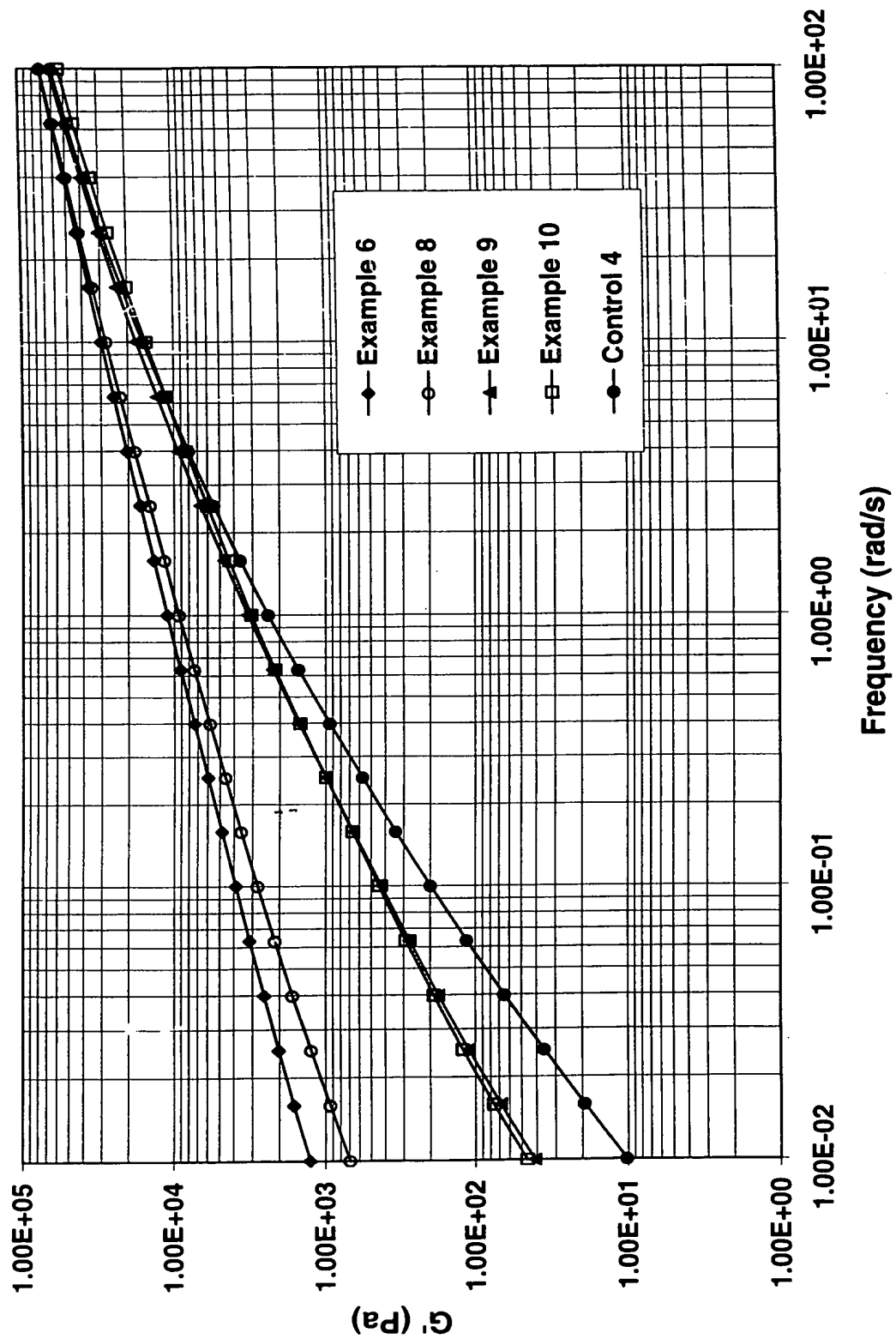


FIGURE 2

G' vs. FREQUENCY for MODIFIED POLYPROPYLENES at 190 degC



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